

FAST GENERATORS OF DIRECT PHOTONS

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Abstract

Three fast generators of direct photons in the central rapidity region of high-energy heavy-ion collisions have been presented. The generator of prompt photons is based on a tabulation of $p + p(\bar{p})$ data and binary scaling. Two generators of thermal direct photons, for hot hadron gas (HHG) and quark-gluon plasma (QGP) scenarios, assume the 1+1 Bjorken hydrodynamics. SPS and RHIC data can be fitted better by scenario with QGP. Predictions for the LHC energy have been made. The generators have been realized as macros for the ROOT analysis package.

1 Introduction

Direct photons are photons not from particle decays. On the quark-gluon level three sub-processes dominate: Compton scattering $gq \rightarrow \gamma q$, annihilation $q\bar{q} \rightarrow \gamma g$ and bremsstrahlung emission $qq(g) \rightarrow qq(g)\gamma$. Photons from initial hard NN collisions are named prompt photons and are the main source at large p_t . They can be described by perturbative QCD (pQCD). In the case of other limit - thermalized system of quarks and gluons, the quark-gluon plasma (QGP), these photons are named thermal photons from QGP.

On the hadron level there are a lot of meson scattering channels: $\pi\pi \rightarrow \rho\gamma, \pi\rho \rightarrow \pi\gamma, \pi K \rightarrow K^*\gamma, K\rho \rightarrow K\gamma, \dots$. First two channels give most contribution. If hadron system is thermalized these photons are named thermal photons from the hot hadron gas (HHG).

Besides the meson rescatterings, photons from decays of short-living resonances, $\omega \rightarrow \pi\gamma, \rho \rightarrow \pi\pi\gamma, a_1 \rightarrow \pi\gamma, \Delta \rightarrow N\gamma, \dots$, make a contribution to direct photons. In the case when the life time of a resonance is less than characteristic time of the nucleus-nucleus collision it is difficult to reconstruct the resonance because the decay hadron (e.g. π) can reinteract with surrounding medium especially if this medium is dense.

Below three fast generators of direct photons are proposed: a generator of prompt photons and two generators of thermal direct photons.

2 Generator of prompt photons

In the paper [1] all existing $p + p(\bar{p})$ data on prompt photons in central rapidity region have been presented as the function $(\sqrt{s})^5 E d^3\sigma^{pp}/d^3p = F(x_T), x_T = 2p_t/\sqrt{s}$. Using a tabulation of this dimensionless function one can estimate the prompt photon spectrum in nucleus-nucleus, A+B, collisions at the impact parameter b : $E d^3N^{AB}(b)/d^3p = E d^3\sigma^{pp}/d^3p \cdot AB \cdot T_{AB}(b)$, where the nuclear overlapping function is defined as $T_{AB}(b) = N_{coll}(b)/\sigma_{in}^{pp}$, where $N_{coll}(b)$ is

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the average number of binary NN collisions. Nuclear effects (Cronin, shadowing) are ignored in this approach.

Fig. 1 demonstrates reasonable agreement of existing RHIC data [2] with results of the generator GePP.C realized as a macro for the ROOT analysis package [3]. Predictions for prompt photons at LHC energy is presented in Fig. 2.

3 Generators of thermal direct photons

For fast generators the Bjorken hydrodynamics(BHD) [4] has been used. It is assumed that during the ion-ion collision the system is mainly expanding in beam direction in a boost-invariant way. Natural variables are the proper time $\tau = \sqrt{t^2 - z^2}$ and rapidity. Thermodynamical variables (pressure, temperature, ...) do not depend on the rapidity but are functions of τ . Viscosity and conductivity effects are neglected.

Main parameters are the initial thermalization time τ_0 and temperature T_0 . Photon yield is proportional to $\sim \tau_0^2$, the spectrum slope is controlled by T_0 . There is third parameter, temperature at freeze-out, T_f . Results depend weekly on it value. $T_f=100$ MeV has been used.

For this simple space-time evolution one can evaluate expression for photon spectrum with the photon emission rate as input which are different for HHG and QGP scenarios. All needed formulas can be found in [5].

3.1 Generator for the HHG scenario

The photon emission rates for processes $\pi\pi \rightarrow \rho\gamma, \pi\rho \rightarrow \pi\gamma$ and $\rho \rightarrow \pi\pi\gamma$ in the HHG scenario have been obtained in [6] using the effective chiral Lagrangian theory with π, ρ and a_1 mesons. Later they were parametrized by formulas in [7]. Rates for the channel $\omega \rightarrow \pi\gamma$ have been taken from [8].

Figs. 3 and 4 show comparison of SPS [9] and RHIC [10] data with results of the generator GeTP-HHG.C realized as a macro. SPS data can be fitted by the BHD with the HHG scenario, except low p_t points. For fitting the RHIC data unreasonable values of parameters should be used, too large $\tau_0=7$ fm/c, and small $T_0=200$ MeV. The HHG scenario is hardly realized at the RHIC energy. At the RHIC energy prompt photons dominate science $p_t=2$ GeV/c while at SPS they are not important up to 4 GeV/c.

3.2 Generator for the QGP scenario

In the QGP scenario of high-energy heavy-ion collisions three phases are assumed: a pure QGP phase, a mixed phase (QGP and HHG coexist) and a pure HHG phase. Ideal baryon free massless parton gas approximation for QGP and ideal massless meson gas approximation for HHG are explored. A first order phase transition at the critical temperature T_c is assumed. Other parameters of the QGP scenario are the number of degree of freedom g_q in QGP defined by the number of colors, N_c , and flavors, N_f , and effective number of degree of freedom g_h in HHG. Time moments between the pure QGP and the mixed phase, τ_c^q , between the mixed phase and the pure HHG, τ_c^h , and time of the freeze-out τ_f are expressed through the parameters.

The photon emission rates for QGP have been evaluated in perturbative thermal QCD applying hard thermal loop (HTL) resummation. Contribution of the next to leading order diagrams (bremsstrahlung and annihilation with scattering) is the same order in α_s as from the

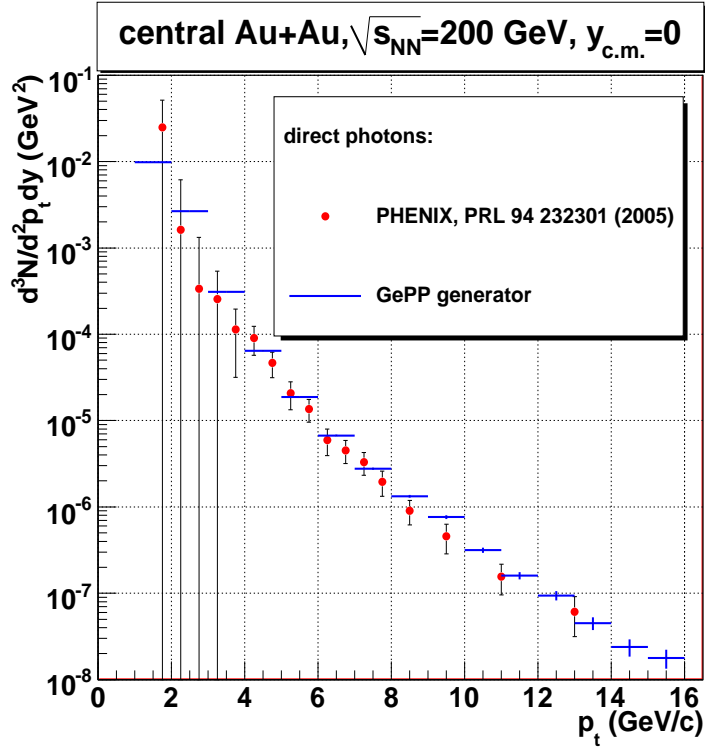


Figure 1: Direct photon spectrum in central Au+Au collisions at RHIC

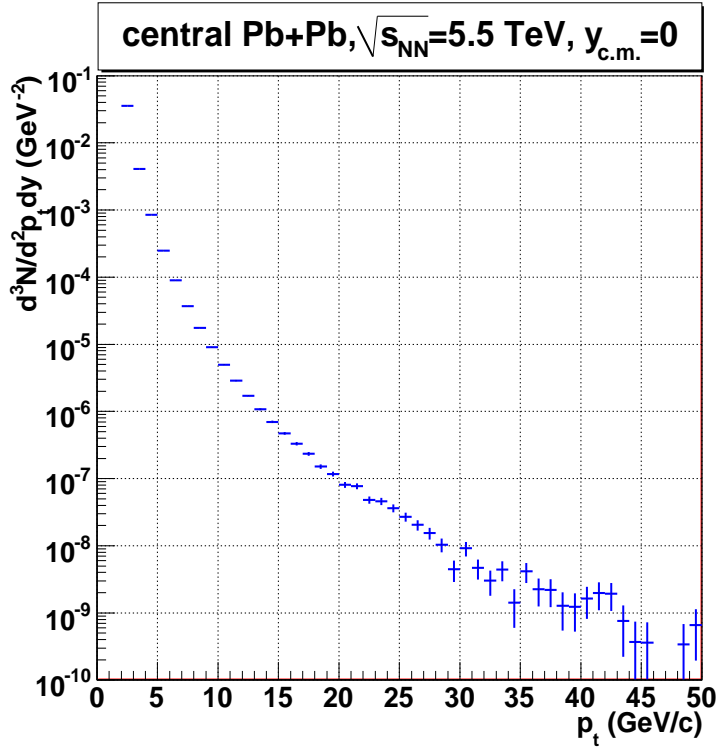


Figure 2: Prompt photon spectrum in central Pb+Pb collisions at LHC

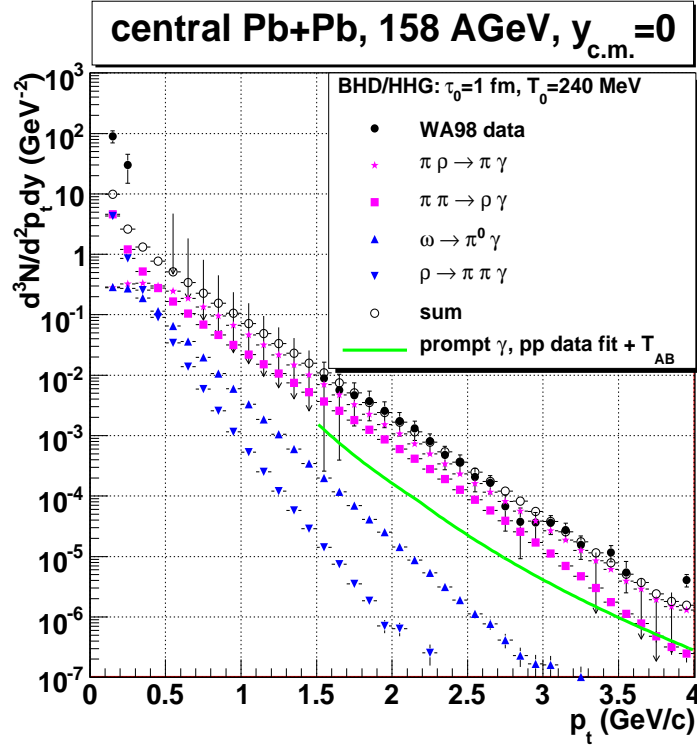


Figure 3: Direct photon spectrum for central Pb+Pb collisions at SPS

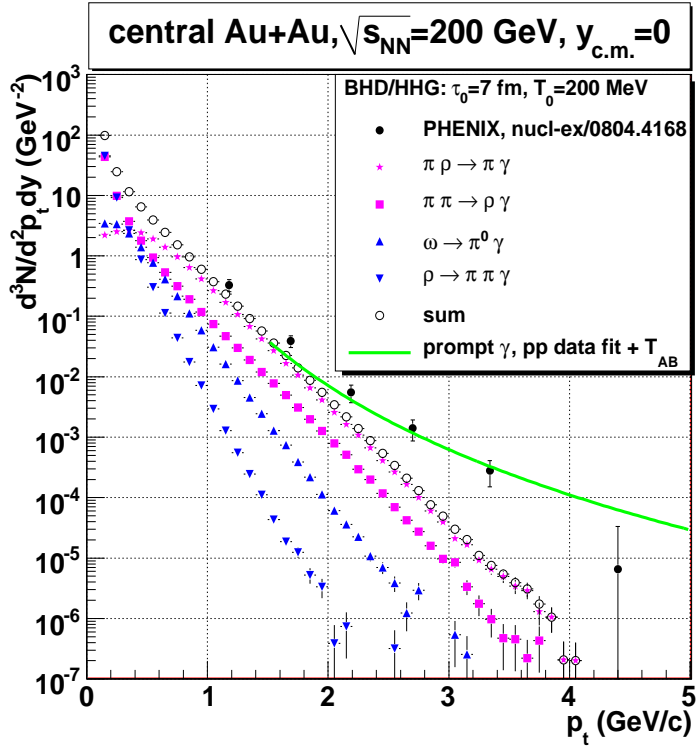


Figure 4: Direct photon spectrum for central Au+Au collisions at RHIC

\sqrt{s} GeV	T_0 MeV	τ_0 fm/c	τ_c^q fm/c	τ_c^h fm/c	τ_f fm/c	dN_γ/dy	INIT CPU
17	340	0.20	1.6	9.5	46.7	14	110 s
200	430	0.15	2.4	14.4	70.8	31	160 s
5500	650	0.10	5.6	33.2	163	173	390 s

Table 1: Characteristics of central collisions at SPS, RHIC and LHC energies in the QGP scenario

leading order diagrams (Compton scattering and $q\bar{q}$ annihilation). This means that thermal photon production in QGP is a non-perturbative mechanism that can not be accessed in perturbative HLT resummed thermal field theory. One must consider the obtained QGP rates as an educated guess.

Figs. 5 and 6 show comparison of the SPS and RHIC data with results of the generator GeTP-QGP.C realized as a macro (parameter values $N_c=3$, $N_f=3$, $T_c=170$ MeV and $g_h=8$ have been used). With the QGP scenario one can try to describe also low p_t SPS data. The RHIC data can be reproduced with reasonable values of τ_0 and T_0 . QGP outshines HHG at $p_t > 2$ GeV/c. One can compare the BHD spectra with 2+1 hydrodynamics results [11]. While spectrum from QGP is almost the same the HHG spectrum is steeper. One of the reasons is the radial flow in the 2+1 case.

Fig. 7 demonstrates predictions for the LHC energy. Parameter values $\tau_0=0.1$ and $T_0=650$ MeV have been chosen the same as in 2+1 hydrodynamics [12]. QGP outshines HHG at $p_t > 2$ GeV/c while in the 2+1 hydrodynamics it happens at 3 GeV/c.

Table 1 summarizes results for SPS, RHIC and LHC energies. Except the initial and time evolution parameters the rapidity densities of thermal direct photons, dN_γ/dy , are pointed out. Though QGP dominates at high p_t its contribution in dN_γ/dy is 10%. In the last column of the table typical CPU time needed to calculate dN/dp_t photon distribution used to randomly chose a p_t value.

4 Summary

Three fast generators of direct photons in the central rapidity region of high-energy heavy-ion collisions have been presented. The generator of prompt photons is based on a tabulation of $p + p(\bar{p})$ data and binary scaling. Two generators of thermal direct photons, for HHG and QGP scenarios, assume the 1+1 Bjorken hydrodynamics. SPS and RHIC data can be fitted better by scenario with QGP. Predictions for the LHC energy have been made. The generators have been realized as macros for the ROOT analysis package. First two of them have been implemented into the FASTMC code of the UHKM package [13].

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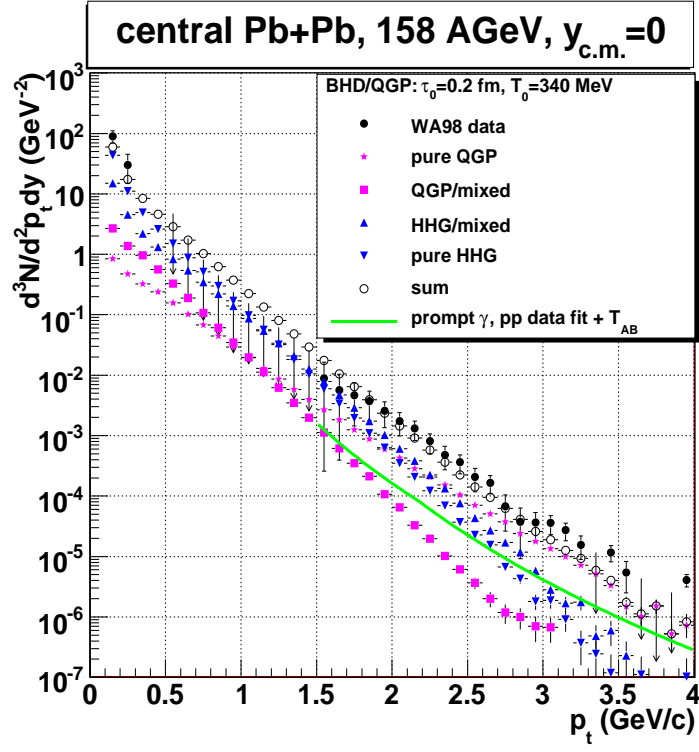


Figure 5: Direct photon spectrum for central Pb+Pb collisions at SPS

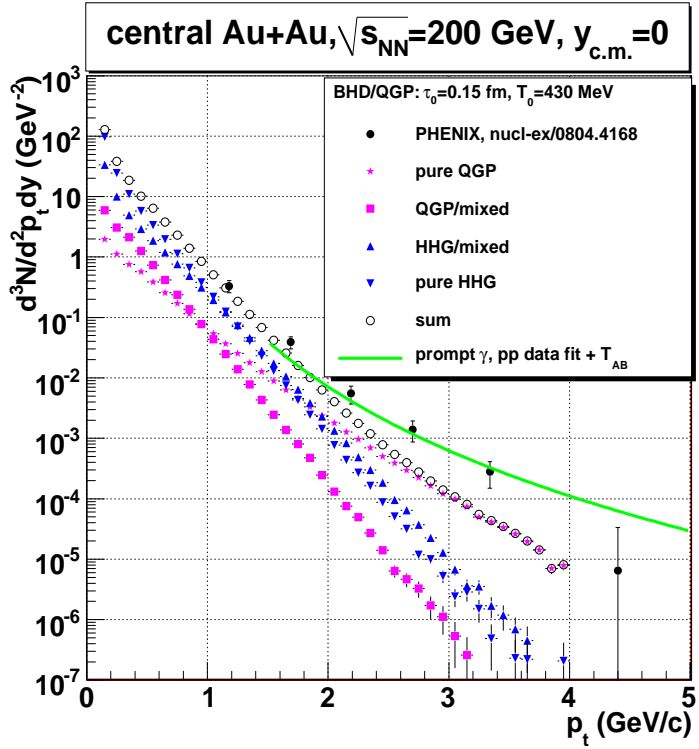


Figure 6: Direct photon spectrum for central Au+Au collisions at RHIC

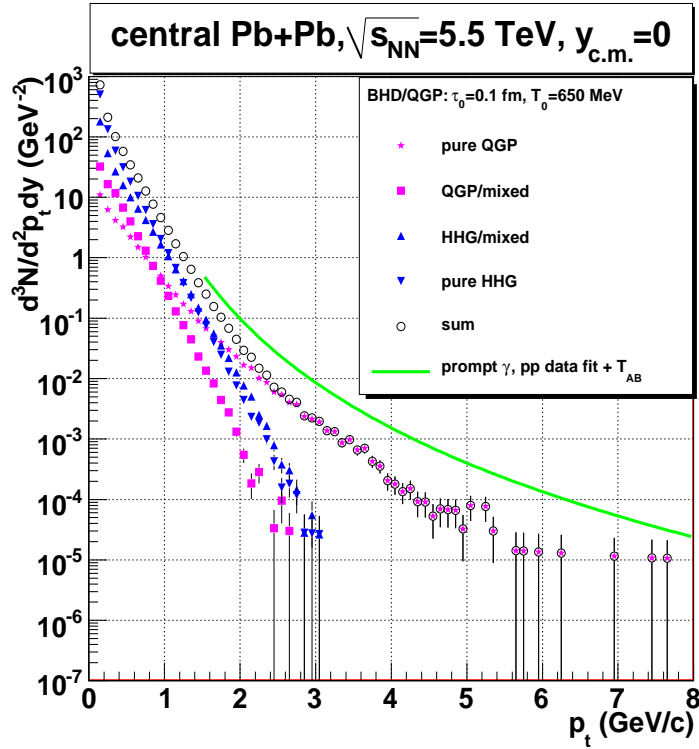


Figure 7: Direct photon spectrum for central Pb+Pb collisions at LHC

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